Spring 2019

# Scientific Communication and CRISPR

Sarah Fleischmann
*Iowa State University*, sarahf1@iastate.edu

Scientific communication and CRISPR

by

**Sarah Lynn Fleischmann**

A creative component submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Plant Breeding

Program of Study Committee:
Jeffrey Wolt, Major Professor
Thomas Lubberstedt

Iowa State University

Ames, Iowa

2019

# ACKNOWLEDGMENTS

I would like to thank my committee chair Dr. Jeffrey Wolt and my committee member Dr. Thomas Lubberstedt, for their guidance and support throughout the course of this research. I would also like to thank the department faculty and staff for making my time at Iowa State University a wonderful experience, and to Michelle Zander in particular for her help and support throughout my time in the program. I want to also offer my appreciation to my colleagues at Syngenta for their support and encouragement, without which this creative component would not have been possible.

Table of Contents

## Abstract

Genome editing technologies have the capability of providing a quick, relatively inexpensive method of plant breeding that could greatly expand breeding efforts across species. CRISPR-Cas9 has become one of the leading forms of genome editing, but the level of investment and number of products developed with the technology will be greatly affected by both regulatory decisions made around the world and the level of consumer acceptance. The ability of scientists who are involved with genome editing research to communicate with non-experts will impact the outcomes of both factors. This paper reviews available literature on scientific communication, provides a high-level discussion on the CRISPR-Cas9 system of genome editing, and links the two topics with a discussion of how scientific communication will affect the utilization of CRISPR-Cas9, providing recommendations for those who wish to engage in the discussion. This review of the literature makes it apparent that it will not be sufficient to solely educate the public about gene editing technologies; rather, a dialogue must be opened that will both educate and address regulatory and consumer concerns in an honest, transparent way.

## Introduction

New genome editing technologies are quickly changing the landscape of plant breeding. The ability to more precisely control where an edit occurs within a genome allows scientists to develop new varieties with novel or improved traits much more quickly and efficiently than is possible with traditional breeding techniques. Additionally, there is the hope that genome editing can gain broad acceptance and can overcome persistent public skepticism concerning acceptability of genetic engineering with transgenics for crop improvement. The CRISPR-Cas9 system in particular has shown promise as being relatively inexpensive and easy to utilize, opening the door for its use in small market and specialty crops that might not otherwise be worth the hefty investment required for traditional genetic modification or the high regulatory costs for genetic engineering. Genome editing is also being used to improve the row crops that have traditionally been improved through transgene insertion. Because the modification that occurs with the CRISPR-Cas9 system does not necessarily involve the insertion of foreign DNA, there is discussion about whether or not certain plant modifications with the system should be subjected to the traditional regulatory process, especially for those modifications that retain no foreign DNA in the finished plant variety (Wolt et al., 2015; Wolt et al., 2016).

With any new technology, and particularly one which affects the world's food supply, communication is vital both for achieving an appropriate level of regulation and for securing public support of the technology. As can be seen with the lack of widespread acceptance for traditional transgenic crops, regulatory approval does not guarantee public approval will follow. Despite the lack of credible scientific evidence that genetically modified crops cause harm, there is a growing movement for labeling of GMO foods at best and an outright ban at worst. Although the CRISPR-Cas9 technology (referred to as CRISPR here) should theoretically reduce or eliminate some of the concerns that people have voiced about transgenetic modification (that is, presence of foreign DNA), the ability to educate the public about this technology will be necessary in order to achieve a strong enough level of public acceptance that the technology is able to be successfully deployed.

With a growing population and a changing climate, it is essential that we utilize every resource available to produce food while limiting the environmental impact of producing that food. Scientists concerned with food production must not shrink from the tough discussions that are occurring around our food supply. Rather, they must become the voice of reason and facts and work to ensure that the public understands what they are doing and why in as transparent a manner as possible. Since many scientists are not explicitly trained to have those discussions, it is helpful to explore an understanding of scientific communication and what constitutes successful communication. These concepts can then be applied both to formal communication events and informal personal conversations. Through consistent, quality communication it may be possible to reach an increased level of understanding of the CRISPR-Cas9 technology in both the public and those who may be making regulatory decisions without an actual background in genetics or plant science.

This paper reviews and analyzes current understanding of scientific communication with a view toward its effect on the use of CRISPR gene-editing technology. While CRISPR shows great promise as a tool for plant breeders, it will require the understanding and deployment of successful scientific communication skills in order to achieve an appropriate level of regulatory oversight and widespread consumer acceptance. Scientists who wish to utilize CRISPR would be well served by working to develop stronger scientific communication skills and using these skills to share their expertise when appropriate with the general public and regulatory agencies before the conversation can be dominated by others who may not understand the technology or who may have conflicting goals and beliefs around the use of gene editing. Finally, this paper will provide recommendations for scientists who wish to successfully engage others in discussions around CRISPR or other science-related topics.

**Scientific Communication**

Scientific communication is a term that can be defined in many ways. At its most basic level, it could be defined as the simple transfer of scientific knowledge or facts between two or more parties. However, successful scientific communication needs to be far more than that simple transfer, particularly in an age in which the general public has an almost infinite amount of information available to them at the touch of a screen or click of a mouse. It becomes even more vital when that easily accessible information has no vetting process, and it is quite possible to spend hours researching a topic online and find few if any peer-reviewed publications. Many peer-reviewed publications require the reader to pay for the article or subscribe to a service in order to read them, further reducing the number of the general public that will actually read peer-reviewed articles. Therefore, most of the public receive their information through secondary sources which may misinterpret or misrepresent scientific knowledge.

Burns et al. (2003) define scientific communication as the use of appropriate skills, media, activities, and dialogue to produce one or more of the following:

A: Awareness

E: Enjoyment

I: Interest

O: Opinion-forming

U: Understanding

In order to achieve any of these outcomes, it is important to remember that people bring their backgrounds, educational experiences, prior knowledge of a topic, biases, ethical and political beliefs, and emotions to the conversation. Consideration of the audience is key, as the social and economic background of the audience will affect how communication is received. The audience will generally need a certain level of scientific literacy in order to be able to read or listen and evaluate different sources of information. It is also important to remember that the best success in conveying information will come from two-way communication. The scientist should not expect to only impart information, but rather to listen to and consider feedback from the audience. Not only can that help the scientist to improve later communication, but it may also result in greater understanding of the topic at hand by all parties involved.

Research has shown that people with already formed opinions are not likely to change their minds based on facts alone (Carter et al., 2016; Lewandowsky et al., 2012). In fact, intuition-based opinions can be strengthened by evidence-based counterarguments; this is known as the backfire effect. Additionally, those people who consider themselves the best informed are more likely to reject scientific evidence that challenges their already formed opinion than are those who are aware that they are ignorant about a particular topic. Bombarding the audience with scientific facts and evidence is not likely to change their view, especially when they are already distrustful of the source of information. One approach that has shown some success is to affirm the audience's worldview before presenting alternative ideas. Carter et al. (2016) surveyed students about their opinions on GMOs prior to and after they attended one or two forums on world hunger in which no instruction was given about GMOs or their ability to be a tool in the fight against hunger. Compared to a control group which did not attend either of the forums, those who were exposed to the information about hunger had a significantly more positive outlook on GMOs, despite the fact that neither event addressed GMOs.

Scientific communication is complicated by the role of media. Newspapers, television, radio programs, and the internet are all capable of quickly disseminating information whether it is true or not. The internet, and social media in particular, provide forums in which people share articles and pictures with a large number of people without necessarily checking the veracity of the information. People tend to share things that evoke an emotional response whether or not it is actually true (Lewandowsky et al., 2012). Additionally, since most media forums are responsive to advertising or sales dollars, there is a tendency for them to sensationalize headlines in order to gain audience attention or to oversimplify a complex issue in order to fit it into the allotted time or space. In one example, the reporting on a publication titled "Toxins in transgenic crop byproducts may affect headwater stream ecosystems" escalated the risk statement from "may harm" all the way to "found to damage" within the span of four days (Wolt, 2012). Without changing the contents of the original article, various media outlets made the findings seem much more definitive and negative simply by crafting an eye-catching headline. Specific details of a study can be too difficult or boring for the general public who is watching the news or reading the newspaper, so a catchy sound bite and a quick summary may be all that is presented. If interested people do not take the time to read the actual research, they can be left with a very incomplete understanding of what was actually presented by the scientist.

To further complicate scientific communication by the media, the pressure to be the first to break a story can result in premature reporting of results and it has been shown that retractions are rarely able to eliminate the original reporting and replace it with correct information (Carter et al., 2016; Lewandowsky et al., 2012). Scientific communication does need to be simplified somewhat in order for the non-scientist to understand concepts without the same level of background expertise that the scientist would have, but too much oversimplification can lead to misunderstanding.  Media outfits can also affect scientific communication by giving time to experts and ideas that are simply not factual in an attempt to create balance in their reporting. This can lead people to question the presence of scientific consensus on a topic even when it does in fact exist.

Risk communication is a specific area of scientific communication that deserves attention, as many people who object to the use of biotechnology in agriculture do so because of perceived risks.  The knowledge-deficit model has previously been applied to explain why the general public perceives risk where the scientific community does not.  This model assumes that the general public, or consumer, is wrong about the risks involved with our food sources whereas the experts are correct.  However, the application of this model relies on an oversimplification of the way in which consumers evaluate the level of risk they perceive to either themselves or the environment and results in the belief that simply educating consumers about the reality of risks presented will be enough to change their "incorrect" perception of risk and bring them in line with the "correct" experts (Hansen et al., 2003).

In reality, people tend to assess risks according to many factors and in general will tolerate a certain degree of risk if they are able to associate a benefit with the risk, although the perceived benefit must apply to the risk taker and not to someone else (Hansen et al., 2003). That tolerance of risk is dependent upon confidence in the risk management systems and not necessarily on the technical risk assessments conducted by regulatory agencies (Slovic, 1993). Perhaps surprisingly, a series of studies (Siegrist & Cvetkovich, 2001) found that people perceived their personal risk to be lower when minor risks were actually reported as opposed to when no risks were reported. They also showed increased confidence in the validity of the assessments when minor risks were reported. These findings may indicate a lack of trust in risk assessments in general or in the organizations that conduct them.

There is little evidence available that risk communication efforts to date have reduced the gap between technical risk assessments and public perception of risk or decision making (Slovic, 1993). This may be attributed to a growing lack of trust in the systems that are in place to provide risk assessment information and analyses. Once people have lost trust in the systems put in place to ensure new technologies are safe, it is incredibly difficult to reestablish that sense of trust. Many have a lower level of trust in the experts and the trustworthiness of regulation itself because of news media placing more attention on negative events than positive, special interest groups influencing risk polices and debates, and a legal system which tends to pit experts against each other (Slovic, 1993). Therefore, it would seem that the scientific community is at a severe disadvantage when it comes to communicating with the public.

In reality, the situation may not be as dire as it seems. In 2014 and 2015, The Carsey School of Public Policy at the University of New Hampshire conducted surveys of almost 1,500 people in an attempt to understand how political party affiliation affects people's trust in scientists on five key issues: vaccines, climate, nuclear power, evolution, and GMOs (Hamilton, 2015). Although their research was mostly aimed at political affiliation, there were some trends in the data that have broader implications. For four out of the five issues (vaccines: 71%; climate: 62%; nuclear: 69%; evolution: 63%) over half of the respondents reported trusting scientists as a source of information. However, trust in scientists was the lowest in regards to GMOs (47%). Increased education level resulted in increased trust in scientists across all five issues regardless of political affiliation. A survey of 1,480 people conducted by the Pew

Research Center in 2016 also addressed the general public's level of trust in scientists connected with genetically modified (GM) foods (Funk & Kennedy, 2016). According to their survey, both those who claimed to be concerned about the issue of GM foods and those who did not claim to be concerned about the issue of GM foods had a similar level of trust in scientists to provide full and accurate information about the health effects of GM foods. Both groups displayed lower levels of trust in food industry leaders to provide accurate information, but the difference was more pronounced in those who claimed to be concerned about GM foods. They also noted that Americans with higher levels of science understanding are more likely to trust scientists to provide accurate information and to believe that the best evidence available influences research findings about GM foods most of the time. These surveys indicate that the audience composition is an important factor when developing successful scientific communication efforts. They also indicate that information coming from scientists associated with corporations tied to the food industry may have a more difficult time establishing trust with the general public.

## The CRISPR-Cas 9 System for Genome Editing

The CRISPR-Cas9 system of genome editing was developed using elements of the defense mechanism the bacterium *Streptococcus pyogenes* deploys against invading viruses (Ferreira et al., 2018; Puchta, 2017). CRISPR (clustered regularly interspaced short palindromic repeats) refers to DNA sequences that can be targeted to precise locations with a genome. In order to achieve the desired edit, a CRISPR-associated nuclease (Cas9) and a guide RNA (gRNA) are designed to target a specific nucleotide sequence proximal to a protospacer adjacent motif (PAM). Since the gRNA can be designed to target a specific sequence in the genome, once the gRNA leads the Cas9 protein to the complementary sequence it cleaves the DNA strand, resulting in a double strand break (DSB). As the DNA is repaired through either homologous repair (HR) or non-homologous end joining (NHEJ), mutations may be introduced to the genome (Ferreira et al., 2018; Wolt et al., 2016). These can take the form of insertions, deletions, sequence replacements, and even base conversions; and in plant systems, represent a valuable source of genetic variation that may be useful for crop improvement. Additionally, template insertion and complete gene insertions or deletions can be directed with the CRISPR-Cas 9 system (Gao, 2018).

The CRISPR-Cas9 system has some definite advantages over the traditional breeding method of introducing variability into a population and searching for useful combinations of genes to exploit. Not only does it allow for targeted edits of specific genes rather than random introduction of allelic variation, it also avoids the introduction of unwanted alleles through crossing and recombination as well as the time required to backcross desired alleles into existing genetic backgrounds. The alleles that are targeted for gene editing will all be affected while the foreign DNA used to deliver the system remains hemizygous, which means that within one generation seed can be generated that is homozygous for the desired edit while the delivery mechanism is segregated out. When null segregant selection is used to eliminate the DNA which encodes the CRISPR-Cas 9 reagents and the edits introduces no foreign DNA, the progeny will be transgene free and undistinguishable from plants that could have resulted from traditional breeding techniques such as mutagenesis (Scheben et al., 2017). The speed and specificity with which gene editing can be deployed has the potential to greatly reduce the costs associated with traditional breeding programs.

There are some aspects of the CRISPR-Cas9 system that require further research and provide opportunities for improved efficiency and reduced cost of the technology. While HR offers the most precise method of modifying the genome, in plants the dominant repair mechanism is NHEJ. With NHEJ mutation induction percentages can approach 100%, while the percentage of successful HR mutations is very low in comparison; therefore, HR requires templates large enough to outcompete NHEJ. This can be particularly problematic in plants that do not handle transformation well (Gao, 2018; Puchta, 2017). From a regulatory standpoint, insertion of 'large' DNA segments as templates or entire genes remains an area of uncertainty regarding necessity for safety assessments. Efforts to improve transformation success (particularly in monocots) have been recently documented and include a method of stimulating growth in transformed tissue rather than nontransformed tissue and targeting embryo slices from mature seeds (Scheben et al., 2017). Other recent improvements to the CRISPR system include the use of replication and biolistic transformation to increase of the amount of available HR repair template, the use of NHEJ as a repair mechanism with more precise edits achieved, and the creation of base conversion edits without a DSB. In addition, new Cas enzymes have been identified and offer new opportunities for editing (Scheben et al., 2017).

As a relatively new technology, the possibilities that exist for the CRISPR-Cas9 system are numerous and exciting. CRISPR has been welcomed as a breeding method that can "produce identical results to conventional methods in a much more predictable, faster, and even cheaper manner" (Gao, 2018). Because the technology is fairly easy and inexpensive to utilize, it provides opportunities to explore gene editing in niche crops that have not been cost-effective to modify through traditional gene modification techniques. In agriculture, there are several examples of crop improvements that have already been made with CRISPR-Cas9. Resistance to powdery mildew in wheat, improved yield under drought stress in maize, increased yield in tomato, and a non-browning mushroom have been accomplished with CRISPR gene edits (Gao, 2018). Additional areas of research include larger groundcherries, increased yield and oil content of soybeans and canola, better tasting and easier to eat fruits and vegetables, and a waxy corn that will be used in adhesives and will also improve taste and texture of frozen and canned foods and dairy products (Taylor, 2019). The door to commercializing gene-edited food products in the United States has been opened by Calyxt with their Calyno High Oleic Soybean Oil made from soybeans edited with the transcription activator-like effector nuclease (TALEN) gene editing system (Gullickson, 2019).

Two main considerations will determine how extensively CRISPR technology is utilized in plant breeding: regulatory decisions and consumer acceptance (Gao, 2018; Ferreira et al., 2018). Because it is possible to segregate out the foreign DNA used to accomplish an edit with CRISPR, it was originally thought that plants modified with the CRISPR system would not be subjected to the same regulatory framework that transgenic plants currently are. The presence of recombinant DNA in the final product is what triggers the regulatory process in many countries, and certain CRISPR-edited plants are similar to those developed with traditional breeding in that they do not have recombinant DNA present in the plant once the process in completed. In those cases where CRISPR is used to insert a transgenic event to a specific site in a genome (a safe-harbor insertion), it would almost certainly trigger regulation. However, that early regulatory opinion has faced opposition from some scientists and civil groups, resulting in re-evaluation of what level of regulation is appropriate for genome-edited crops (Wolt et al., 2016).

Although CRISPR-edited crops may escape some of the regulatory scrutiny applied to traditional GMOs, it is still vital to assess the safety of those crops on a case-by-case basis. This does not mean regulation is needed in all cases, however. It may be very possible for scientists and developers to enable self-governance for products developed by this technology as for instance in establishing best practices for genome editing of plants (Wolt, 2017). While many regulators support the idea that the phenotype that results from genome editing should be the basis for evaluating its safety (also known as product-based regulation), pressure from political and consumer groups can cause those product-based evaluations to give way to process-based regulation in which the method used to develop the plant is considered rather than the end result. Wolt et al. (2015) outlined a schema (see Fig 1 below) for anticipated regulatory characterization that considers the technique used to perform the edit as well as the resulting product. To summarize, lower levels of regulatory scrutiny are anticipated for small edits involving NHEJ with no recombinant DNA left in the final product; case-by-case evaluations of HR edits involving few nucleotides; and standard regulation of site-directed transgene insertion are expected. Governments are starting to determine how they will regulate gene-edited crops: see Figure 2 below for the current regulatory status of CRISPR-edited crops in different regions.

| Category / Method | Category 1 Transient expression resulting in site-specific DSB and repair | Category 2 Stable genomic introduction of rDNA with intermediate steps to generate transgene-free null segregants | Category 3 Stable genomic integration of recombinant DNA |
|---|---|---|---|
| **SDN1*** Site-directed random mutation involving NHEJ | Low | • Low for deletions<br>• Case-by-case for addition<br>• Higher as size of insertion increases | N/A |
| **SDN2** site-directed homologous repair involving one or very few nucleotides | Case-by-case | Case-by-case | N/A |
| **SDN3** site-directed transgene insertion | N/A | N/A | High, moderated for well characterized insertion sites |

Figure 1: *Schema of anticipated regulatory characterization taken from "The Regulatory Status of Genome-edited Crops" (Wolt et al. 2015)*

| Government | Decision | Date of Decision | Source |
|---|---|---|---|
| Argentina | Case-by-case | May 2015 | Global Engage |
| Brazil | Case-by-case | Jan 2018 | Global Engage |
| Canada | Regulates all novel traits | Nov 2018 | www.inspection.gc.ca |
| Chile | Case-by-case | 2017 | Global Engage |
| EU | Same regulation as traditional GM | July 2018 | Nature.com |
| Japan | No safety screens necessary | March 2019 | Sciencemag.org |
| United States | Not regulated if not a plant pest | March 2018 | www.usda.gov |

Figure 2: *Current regulatory decisions regarding gene edited plants and date of announcement; see reference list for full links to sources.*

Key scientific questions with implications to the safety and regulation of genome edited plants include the source of the editing machinery, the nature and specificity of the edit, the nature of the derived trait, the post-edit trait segregation, and the performance of the crop phenotype (Wolt et al., 2016). Of these, off-target edits have been closely scrutinized due to the possibility of deleterious effects arising from unanticipated changes within the genome. Off-target edits happen when the Cas9 protein binds in a region other than the target region and creates a double strand break that results in genome changes at other than the target position. There have been conflicting studies, some of which show that off-target effects in plants can be found with Cas9 and some that show a lack of off-target effects (Puchta, 2017). Efforts to improve the specificity of the edit include the use of better bioinformatics tools to guide gRNA creation, the development of an improved Cas9 variant that has maintained the cutting efficiency while reducing off-target effects and the development of anti-CRISPR proteins which can also reduce off-target edits (Ferreira et al., 2018; Wolt et al., 2016). Whole genome sequencing (WGS), targeted deep sequencing (TDS), and Cas9 binding assays can be used to find off-target edits, but each method presents some weaknesses. WGS is dependent upon the availability and accuracy of a reference genome and even when reference genomes are available, the native variation in cultivated crops (100s to 1000s of SNPs or indels) means the signal associated with genome editing will most certainly remain undetected. Targeted deep sequencing should predict off-target edits but it requires bioinformatics tools to identify near-homologous sites and will only assess predicted sites. As reference genomes and bioinformatics tools mature, the ability to predict, locate, and even prevent off-target edits should increase. It is important to note that the reduction of off-target edits may be more important for increased acceptance of the technology and increased efficiency of use rather than increased safety because off-target edits that result in an undesirable phenotype should be discarded through selection during the plant breeding process (Wolt et al., 2016); however, greater understanding of the frequency and severity of these unintended edits is necessary for appropriate regulatory decisions as well as increasing the chance of scientific and public acceptance of the technology.

## **How Scientific Communication will affect CRISPR use and regulation**

Once regulatory decisions have been made, consumer acceptance will be the second factor that will affect how widely the CRISPR-Cas9 system is used. If people are not willing to consume foods produced with plants that have been engineered with CRISPR, the lack of a market will restrict further investment into the technology whether or not it is safe and efficient to utilize.

With traditional GMOs, the lack of public support has led to the development of a strict and costly regulatory system (Blancke et al., 2015). If CRISPR and other genome editing technologies are eventually classified as a GMO it will result in a long and complicated approval process, increasing the cost of registration such that it will limit the development of products to high value commercial crops and probably to large companies that already have the infrastructure in place to handle the regulatory requirements. However, there is some concern that the public could interpret the exclusion of genome editing technologies from current regulation structure as an attempt to push "new GMOs" through under the radar (Malyska et al., 2016).

The existence of anti-GMO groups such as the Non-GMO Project, which provides a certification and labeling process for manufacturers to declare that their products are free of GMO ingredients, shows that there is enough concern among the public that some food producers find it worth their time and investment to market to those who are worried about the safety of GMOs. These groups have used the power of intuition to promote their cause, and once people have developed intuitive expectations they work to justify their beliefs by finding information that supports those beliefs (Blancke et al., 2015). Furthermore, many people rely on information from non-governmental organizations (NGOs) that are critical of peer-reviewed science to help form opinions about GMOs (Lewandowsky et al., 2012). Before these groups have a chance to dominate the conversation and convince the general public that genome editing is just another way to create a GMO, scientists need to engage the public in open, transparent dialogue about what genome editing is, how it works, and what the risks and benefits of it are. The development and utilization of strong scientific communication skills is vital to any scientist who wishes to successfully join the discussion around CRISPR. The following section of this paper will provide recommendations to consider while planning and participating in that dialogue.

## Recommendations

The first consideration when planning a communication effort is who the audience will be. Scientists who wish to communicate with others about CRISPR may be addressing regulatory agencies, scientific peers who do not specialize in CRISPR, or the general public. While this consideration is not inherently different from any other form of communication, it is important to consider the level of scientific detail to include. Regulatory agencies may require a finer level of detail, depending on the goal of the communication. Scientific peers will likely have a greater ability to read technical communications than the general public. The general public will likely have varying levels of familiarity with the scientific process and differing abilities to comprehend technical knowledge. Narrowing down the general public to particular groups whenever possible is beneficial since there are many sub-groups beyond regulatory agencies and fellow scientists. For instance, communication with a group of adults concerned about food safety would take a different form than communication with a group of high school students from a science club.

The next consideration should be what the goal of the communication is. Because successful communication relies on dialogue, it is important to consider both the goal of the communicator as well as the goal of the expected audience. Understanding ahead of time what the audience expects to gain from the dialogue will help to shape that initial exchange of information. With CRISPR, it is likely that the audience brings in previously held beliefs and concerns about the safety of the food supply and how genome editing can affect that safety. The audience might be interested in the information largely due to fears that have been raised by other sources of information and those fears will have to be addressed before they are willing to consider new information.  On the other hand, the audience might simply be curious about a new technology that is gaining media attention and be open to learning without preconceived ideas.  It is also important for the communicator to understand what outcome is desired.  The goal could be persuasive communication about the safety and benefits of CRISPR or it could be simply to educate people about how it works.

A third decision to be made is how the communication is going to be disseminated.  The format for communication could be a scientific conference, a public hearing or meeting of some type, or social media.  Each different venue will require a different style of presentation. Conferences and meetings frequently provide a format for answering questions which promotes dialogue, helps scientists understand what common concerns are, and allows the scientist to meet the audience on common ground, which has been found to be more effective than widespread communication (Blancke et al., 2017).  Social media has drastically changed the communication landscape and presents difficulties as well as opportunities for dialogue that did not previously exist.  While it is easy to dump information onto social media in a "push" mode, it also provides the opportunity for dialogue with interested parties if comments are read and responses are made. However, social media also provides an avenue for scientists to be attacked by those who disagree with the information presented and those who choose to utilize that venue must be prepared to respond to those attacks calmly and professionally (Blancke et al., 2017).  It is hard to ignore the reach of social media, but it is important to remember that social media is driven largely by income from advertising and there is a lack of quality control of the information that is available.  Also, people tend to pay attention to information that agrees with their preconceived beliefs and pool into echo chambers where those beliefs are not challenged, which may reduce the impact of the communication (Weingart et al., 2016).

Once the audience, goals, and format have been decided, details specific to scientific communication and CRISPR can be addressed. Any affiliation that might seem to provide a conflict of interest should be disclosed at the start of any communication and questions related to that affiliation should be anticipated and answered openly and honestly. Industry scientists can make every effort to follow proper methods and communicate results accurately, but the perception of industry influence can exist and must be addressed. It is necessary in scientific communication to avoid the use of jargon, particularly with the general public. Jargon provides an immediate barrier to understanding if the lay person is not able to decipher what the scientist is saying. It is also important to avoid a condescending tone, which can lead the audience to believe that their concerns are being belittled or ignored.

With scientific communication, trust must be established between the audience and the communicator. Irwin and Horst (2016) mention that the credibility of communication and trust in the communicator are both highly significant for scientific communication, and Weingart and Guenther (2016) claim that people are likely to use their level of trust in a communicator to decide whether or not to accept the message being presented. One of the methods of establishing trust with the audience is to tell your story as a scientist prior to delivering the main message. Explaining your background, how you became interested in science, and why you chose your field of expertise helps the audience get to know you somewhat and to see you as a person and not just a public relations figure. It also helps to provide context for what you are about to communicate. Beginning the communication with an explanation of why it is important and what you would like the audience to gain from it will help prepare the audience to receive the message.  It is important to relate the content of your presentation to the needs or desires of the audience so they can consider how what you are communicating is beneficial to them or how it will impact them personally.  If they begin to trust you as a communicator and to relate what you present to their own lives, they are more likely to reflect on what is presented with an open mind.

As mentioned above, the most effective form of communication is a dialogue and some audience concerns can be anticipated.  Blancke et al. (2017) found that when discussing GMOs the debate usually ended up being about items not inherently related to genetic engineering, which will likely hold true for discussions about CRISPR as well.  Questions about the patent process, herbicide resistance, farming practices in general, and seed saving tend to come up in these discussions and their recommendation is to address those concerns as successfully as possible while demonstrating that they are not inherently tied in to GMOs.  The benefits of CRISPR should be highlighted with an effort to showcase those that will positively impact the consumer directly rather than just the producer, and a transparent discussion of risks involved as well.  Unrelated concerns that arise should be addressed when possible and if it is not possible to provide a sufficient answer on the spot, follow up communication with the interested parties should be executed.  Illingworth (2017) recommends a follow up visit by the scientist or an invitation to visit the workplace if possible.

Answering questions and scheduling follow up communication prevents the ineffective one-way push of information from scientist to audience and allows the scientist to learn what is perceived by the audience as important or where there is a barrier to understanding (Illingworth, 2017).  This can help to shape further communication efforts and start a continuous improvement cycle in which the scientist becomes more confident in communicating with outside parties and develops more effective communication skills that will aid in future efforts.  Informal communication with family, friends, and colleagues can also help increase their knowledge of CRISPR and provide an opportunity for the scientist to practice communication skills that will be useful in more formal communication settings.

## **Conclusions**

Genome editing with CRISPR-Cas9 has the potential to address many of the needs of the plant breeding community, but only if appropriate regulatory decisions are made and consumers are comfortable with the resulting products. With a burgeoning population and climate change affecting agriculture, the world needs to utilize every safe technology available to produce sufficient amounts of food in such a challenging environment. Proper use of scientific communication skills will help scientists address the concerns of the general public and regulatory agencies around the use of genome editing, resulting in increased public acceptance and appropriate regulatory systems.

## References

Blancke, S., Breusegem, F. V., Jaeger, G. D., Braeckman, J., & Montagu, M. V. (2015). Fatal attraction: The intuitive appeal of GMO opposition. *Trends in Plant Science*,*20*(7), 414-418. doi:10.1016/j.tplants.2015.03.011

Blancke, S., Grunewald, W., & Jaeger, G. D. (2017). De-Problematizing ‘GMOs’: Suggestions for Communicating about Genetic Engineering. *Trends in Biotechnology*,*35*(3), 185-186. doi:10.1016/j.tibtech.2016.12.004

Burns, T. W., O’Connor, D. J., & Stocklmayer, S. M. (2003). Science Communication: A Contemporary Definition. *Public Understanding of Science*,*12*(2), 183-202. doi:10.1177/09636625030122004

Callaway, E. (2018, July 25). CRISPR plants now subject to tough GM laws in European Union. Retrieved April 6, 19, from https://www.nature.com/articles/d41586-018-05814-6

Carter, B. E., Conn, C. C., & Wiles, J. R. (2016). Concern About Hunger May Increase Receptivity to GMOs. *Trends in Plant Science*,*21*(7), 539-541. doi:10.1016/j.tplants.2016.05.003

Ferreira, R., David, F., & Nielsen, J. (2018). Advancing biotechnology with CRISPR/Cas9: Recent applications and patent landscape. *Journal of Industrial Microbiology & Biotechnology*,*45*(7), 467-480. doi:10.1007/s10295-017-2000-6

Funk C, Kennedy B. The New Food Fights: U.S. Public Divides Over Food Science. Pew Research Center 2016; http://www.pewinternet.org/2016/12/ 01/the-new-food-fights/

Gao, C. (2018). The future of CRISPR technologies in agriculture. *Nature Reviews Molecular Cell Biology*,*19*(5), 275-276. doi:10.1038/nrm.2018.2

Government of Canada, Canadian Food Inspection Agency, & Plant Health and Biosecurity Directorate. (2018, November 14). Questions and Answers: New Plant Breeding Techniques. Retrieved April

6, 19, from http://www.inspection.gc.ca/plants/plants-with-novel-traits/general-public/new-plant-breeding-techniques/eng/1541800629219/1541800629556

Gullickson, G. (2019, January 22). High-Oleic Soybeans Out of the Lab, Into the Field. Retrieved April 05, 19, from https://www.agriculture.com/crops/soybeans/out-of-the-lab-into-the-field

Hamilton L. Conservative and liberal views of science: Does trust depend on topic? Carsey Research. 2015;45 http://scholars.unh.edu/cgi/viewcontent.cgi ?articleD1251&contextDcarsey

Hansen, J., Holm, L., Frewer, L., Robinson, P., & Sandøe, P. (2003). Beyond the knowledge deficit: Recent research into lay and expert attitudes to food risks. *Appetite,41*(2), 111-121. doi:10.1016/s0195-6663(03)00079-5

Illingworth, S. (2017). Delivering effective science communication: Advice from a professional science communicator. *Seminars in Cell & Developmental Biology,70*, 10-16. doi:10.1016/j.semcdb.2017.04.002

Irwin, A., & Horst, M. (2016). Communicating trust and trusting science communication — some critical remarks. *Journal of Science Communication,15*(06). doi:10.22323/2.15060101

Lewandowsky, S., Ecker, U. K., Seifert, C. M., Schwarz, N., & Cook, J. (2012). Misinformation and Its Correction. *Psychological Science in the Public Interest,13*(3), 106-131. doi:10.1177/1529100612451018

Malyska, A., Bolla, R., & Twardowski, T. (2016). The Role of Public Opinion in Shaping Trajectories of Agricultural Biotechnology. *Trends in Biotechnology,34*(7), 530-534. doi:10.1016/j.tibtech.2016.03.005

NormileMar, D. (2019, March 22). Gene-edited foods are safe, Japanese panel concludes. Retrieved April 6, 19, from https://www.sciencemag.org/news/2019/03/gene-edited-foods-are-safe-japanese-panel-concludes

Puchta, H. (2017). Applying CRISPR/Cas for genome engineering in plants: The best is yet to come. *Current Opinion in Plant Biology*,*36*, 1-8. doi:10.1016/j.pbi.2016.11.011

Scheben, A., Wolter, F., Batley, J., Puchta, H., & Edwards, D. (2017). Towards CRISPR/Cas crops - bringing together genomics and genome editing. *New Phytologist*,*216*(3), 682-698. doi:10.1111/nph.14702

Secretary Perdue Issues USDA Statement on Plant Breeding Innovation. (n.d.). Retrieved April 6, 19, from https://www.usda.gov/media/press-releases/2018/03/28/secretary-perdue-issues-usda-statement-plant-breeding-innovation

Siegrist, M., & Cvetkovich, G. (2001). Better negative than positive? Evidence of a bias for negative information about possible health dangers. *Risk Analysis : An Official Publication of the Society for Risk Analysis*, *21*(1), 199-206.

Slovic, P. (1993). Perceived Risk, Trust, and Democracy. *Risk Analysis*,*13*(6), 675-682. doi:10.1111/j.1539-6924.1993.tb01329.x

Taylor, A. P. (n.d.). Companies Use CRISPR to Improve Crops. Retrieved March 25, 2019, from https://www.the-scientist.com/bio-business/companies-use-crispr-to-improve-crops-65362

To regulate or not to regulate: Current legal status for gene-edited crops. (n.d.). Retrieved April 6, 19, from http://www.global-engage.com/agricultural-biotechnology/to-regulate-or-not-to-regulate-current-legal-status-for-gene-edited-crops/

Weingart, P., & Guenther, L. (2016). Science communication and the issue of trust. *Journal of Science Communication*,*15*(05). doi:10.22323/2.15050301

Wolt, Jeffrey. (2012). Balancing the risks and benefits of food innovation: Regulatory and public perceptions.

Wolt, J. D., Wang, K., & Yang, B. (2015). The Regulatory Status of Genome-edited Crops. *Plant Biotechnology Journal*,*14*(2), 510-518. doi:10.1111/pbi.12444

Wolt, J. D., Yang, B., Wang, K., & Spalding, M. H. (2016). Regulatory aspects of genome-edited crops. *In Vitro Cellular & Developmental Biology - Plant*,*52*(4), 349-353. doi:10.1007/s11627-016-9784-3

Wolt, J. D., Wang, K., Sashital, D., & Lawrence-Dill, C. J. (2016). Achieving Plant CRISPR Targeting that Limits Off-Target Effects. *The Plant Genome*,*9*(3), 0. doi:10.3835/plantgenome2016.05.0047

Wolt, J. D. (2017). Safety, Security, and Policy Considerations for Plant Genome Editing. *Progress in Molecular Biology and Translational Science Gene Editing in Plants*, 215-241. doi:10.1016/bs.pmbts.2017.03.005